SOME EXAMPLES OF THE DETECTION OF JET STREAMS FROM TIROS PHOTOGRAPHS

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ABSTRACT

TIROS photographs of cloud patterns in the vicinity of the jet stream are examined and compared with surface, upper air, and pilot-report data. It is found that with certain conditions of lighting and satellite attitude the northern edge of the cirrus cloud shield, which lies immediately south of the jet, can be easily identified by a shadow cast by the higher cloud deck on the lower underlying surface. This shadow identifies the cloud structure associated with the jet stream. Differences in texture and pattern also help to identify the northern limits of the high-level cirrus and thus aid in positioning the jet stream.

In recent years many investigators have studied the relationship of clouds to the jet stream. Sawyer and Ilett [1], Schaefer [2], and Conover [3] have studied jet stream clouds from the ground, while Murray [4], McLean [5], Kadlec [6], and others have used aircraft reconnaissance. Most of these studies reached similar conclusions regarding the type of clouds and the configuration of the cloud patterns associated with the jet. There is now considerable evidence that many of these jet stream cloud patterns can be detected in TIROS photographs.

One feature which these studies have shown is the abrupt ending of the shield of high cloudiness along the jet core. Kadlec, in his analysis of 414 flights through jets, showed this break in the cloud to be associated with certain specific jet stream configurations. With this in mind, we studied TIROS pictures in the vicinity of known jet stream axes to see if the expected cloud distributions could be detected in the pictures. The cases studied revealed that the northern edge of the middle and high cloud shield associated with the jet was always detectable when there were no low clouds to confuse the pattern. In TIROS pictures, this sharp, distinct edge on the cold side of the cloud shield can be distinguished from other cloud boundaries by its straight, smooth appearance and its extensive length. The edge of this high cloud shield could also often be identified where it overlay a deck of lower cloud.

One factor which enables the analyst to detect this edge is the difference in texture between the high clouds and the lower ones. A second factor is that, under certain conditions, the high clouds cast a shadow on the lower clouds. The shadow varied from 5 to about 16 mi. wide in the cases studied. The appearance of this shadow is dependent on the sun angle, the relative height difference between the higher cloud shield and the tops of the underlying low cloud, and the angle from which the cloud shield is observed by the satellite. A schematic illustration of this effect is shown in figure 1. In the TIROS pictures studied, this shadow clearly outlined the northern edge

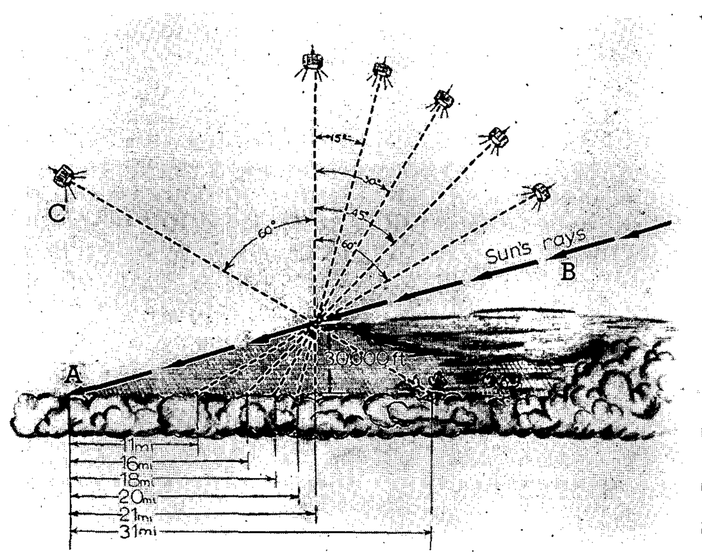

FIGURE 1.—How the apparent size of shadows visible in TIROS pictures is a function of the sun angle, the height difference between the cloud casting the shadow and its underlying surface, and the attitude of the satellite. In this example, a relatively low sun angle of 15° and a height difference of 30,000 ft. between two cloud decks produce a shadow on the surface of the lower cloud layer which begins at point A and extends to the right. When the attitude of the satellite is such that the camera is pointing parallel to the sun's rays and away from the sun (point B), none of this shadow is visible in the pictures. If the satellite attitude is such that it points straight down, a shadow 21 mi. wide is visible. The width of shadow visible for intermediate attitudes of the satellite is also shown. Finally, if the attitude of the satellite is such that it is pointing back toward the sun (point C) and "sees" under the edge of the higher cloud, the shadow appears to be as wide as 31 mi.

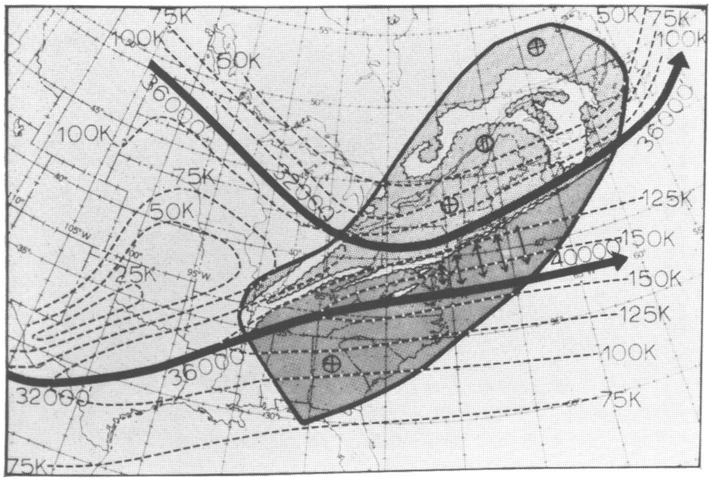

FIGURE 2.—Nephanalysis of pass 0922 (TIROS VI, 1355 GMT, November 20, 1962). The 200-mb. isotach analysis for 1200 GMT and the positions of the jet at that level are superimposed. The height of the maximum wind is entered along the jet stream positions. The darker shading denotes the high cloud shield and the lighter shading, lower cloud. This convention applies to similar figures that follow.

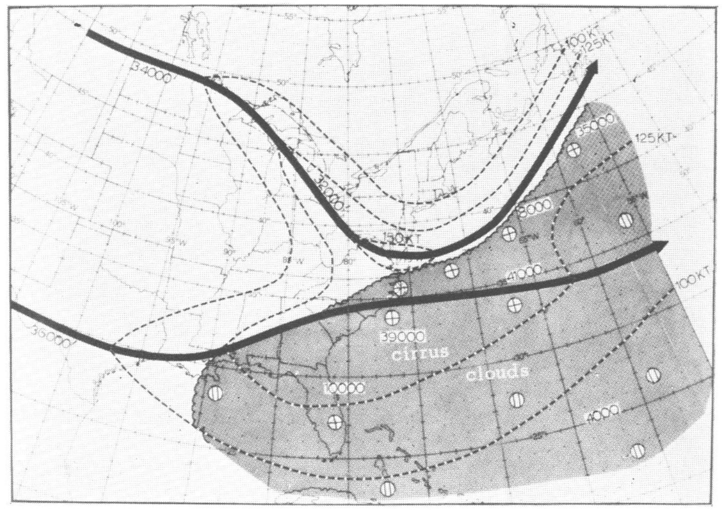

FIGURE 3.—Kadlec's model (Type C) of the cirrus cloud pattern associated with two converging jet streams.

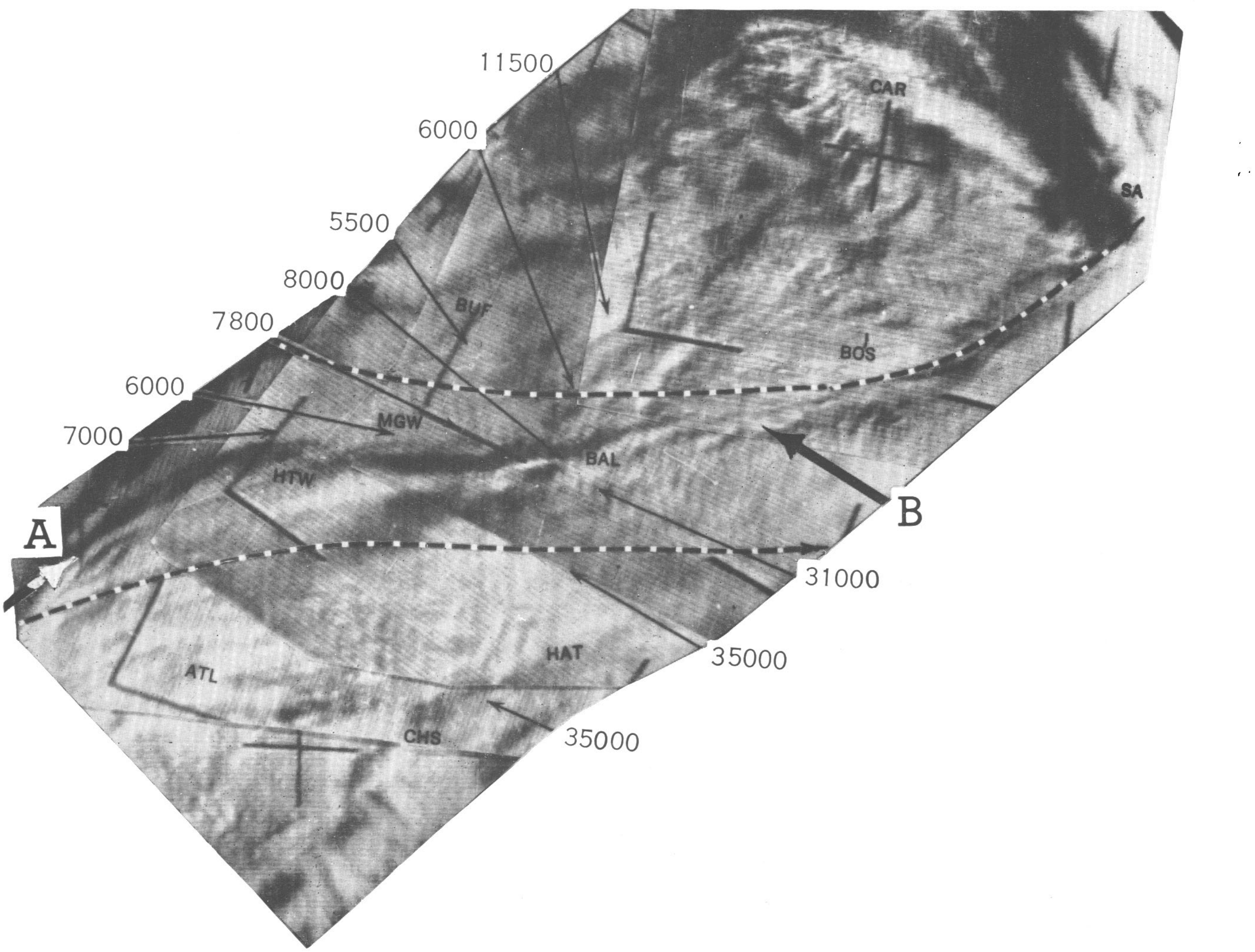

FIGURE 4.—A mosaic of pass 0922 with height of cloud tops in thousands of feet, as reported by pilots within 1 hr. of picture time. The dashed lines are the position of the jet stream at 200 mb. as analyzed by NMC. Note the dark streak just to the south of the northernmost jet and extending from the head of arrow A to the head of arrow B.

of the high clouds and made the discontinuity in cloud height easy to identify.

In the cases to be described the cloud structure in the vicinity of the jet as located by conventional data was compared in detail with the cloud pattern visible in the TIROS pictures.

The first case covers an area over the northeastern United States (fig. 2) observed by TIROS VI on orbital pass 0922 at 1355 GMT November 20, 1962. Superimposed on the nephanalysis are the jet streams and the maximum wind analysis prepared by the National Meteorological Center (NMC).

The configurations of the jet streams are quite similar to Kadlec's type C jet stream and cirrus model (fig. 3). According to Kadlec, when a polar jet with cyclonic curvature and a subtropical jet with anticyclonic curvature form a converging pattern, an area of extensive cirrus occurs both upstream and downstream from the area of confluence. Upstream, the cirrus cloud shield lies along and to the south of the subtropical jet and extends to the area where the two jet streams converge. This point of convergence is usually where the maximum wind speed in the two jet streams occurs. Near this isotach maximum, the edge of the high cloud shield crosses to the north of the subtropical jet and extends downstream just to the south of the polar jet.

Figure 4, a mosaic of pass 0922 with the NMC jet stream positions superimposed, covers the area from northeastern Mississippi to southern Labrador outlined by the nephanalysis in figure 2. The interesting feature in the mosaic is the apparent dark streak that extends from central Kentucky to near Baltimore, Md. (BAL), and then east-northeastward toward Sable Island (SA). This streak is 50 to 75 mi. south of the analyzed position of the polar jet stream (dashed line) and parallel to it.

In the nephanalysis as originally prepared (fig. 2), this dark streak was analyzed as a narrow clear area. Ground station observations nearest in time to the satellite pictures (fig. 5) show overcast conditions at all stations in the vicinity of the dark streak. This evidence, at least in part, supports the proposition that this streak is a shadow cast by the higher cloud deck on lower clouds.

To ascertain the vertical cloud distribution in the vicinity of the streak, radiosonde data for 1200 GMT were plotted (fig. 6). The data from the stations south of the polar jet, in what should be the cirrus area, indicate nearly saturated conditions in the upper levels, while most stations to the north of the streak show much dryer air above 10,000 ft.

Pilot reports made within 1 hr. of the satellite pictures were collected and figure 4 shows the height of the cloud tops as indicated by these reports. Only those reports indicating clear skies above flight level are shown in this figure. The height of the cloud tops changes abruptly from over 30,000 ft. in the area south of the streak, where the cirrus shield would be expected, to about 6,000 ft. in

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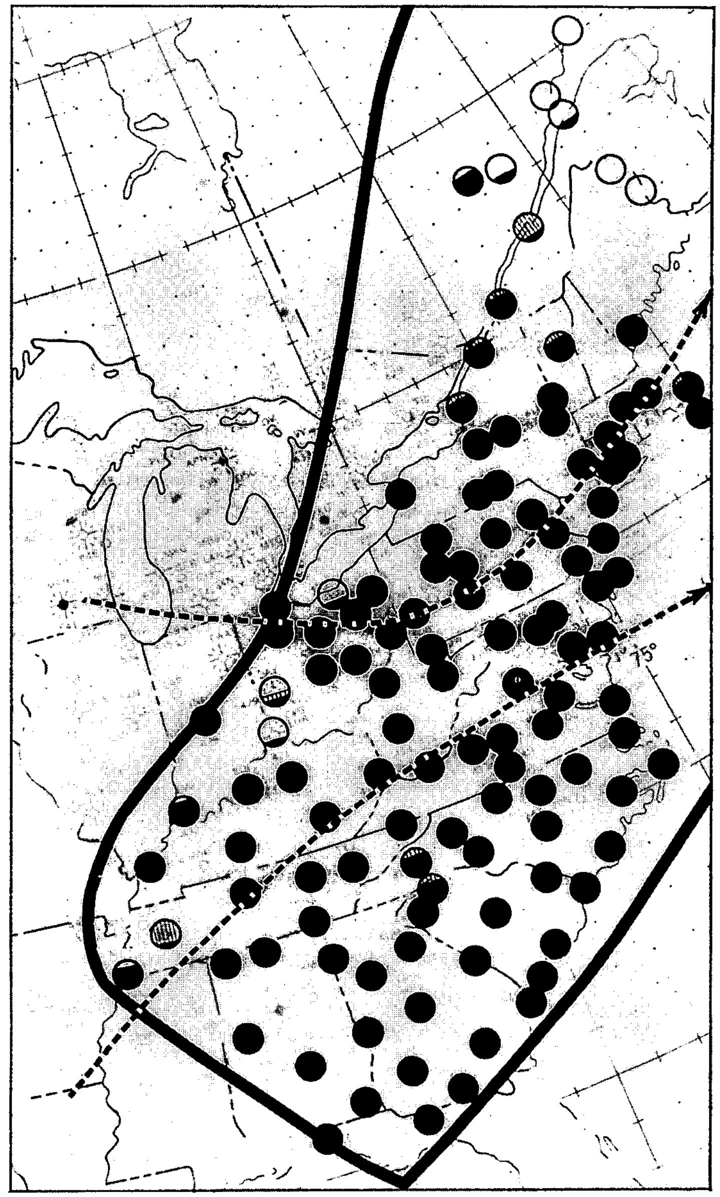

FIGURE 5.—Cloud cover chart for 1400 GMT, November 20, 1962. The dark portion of the station circle denotes the combined amount of low and middle clouds and the hatched portion the amount of high clouds, both as reported from the ground. Open circles indicate clear skies. The dashed lines are the 200-mb. jet streams.

the region north of the streak. This change in height takes place over a small distance as evidenced by the report of cloud tops of 31,000 ft. in the vicinity of Baltimore, while 20 mi. to the west the tops are reported to be 8,000 ft. Two pilots over western Maryland and northern Virginia reported that the top of the overcast was 5,000 to 6,000 ft., but that a higher cirrus cloud deck was visible to the south. All of the reports north of the streak indicate cloud tops below 12,000 ft., with most of them in the 6,000 to 8,000 ft. range.

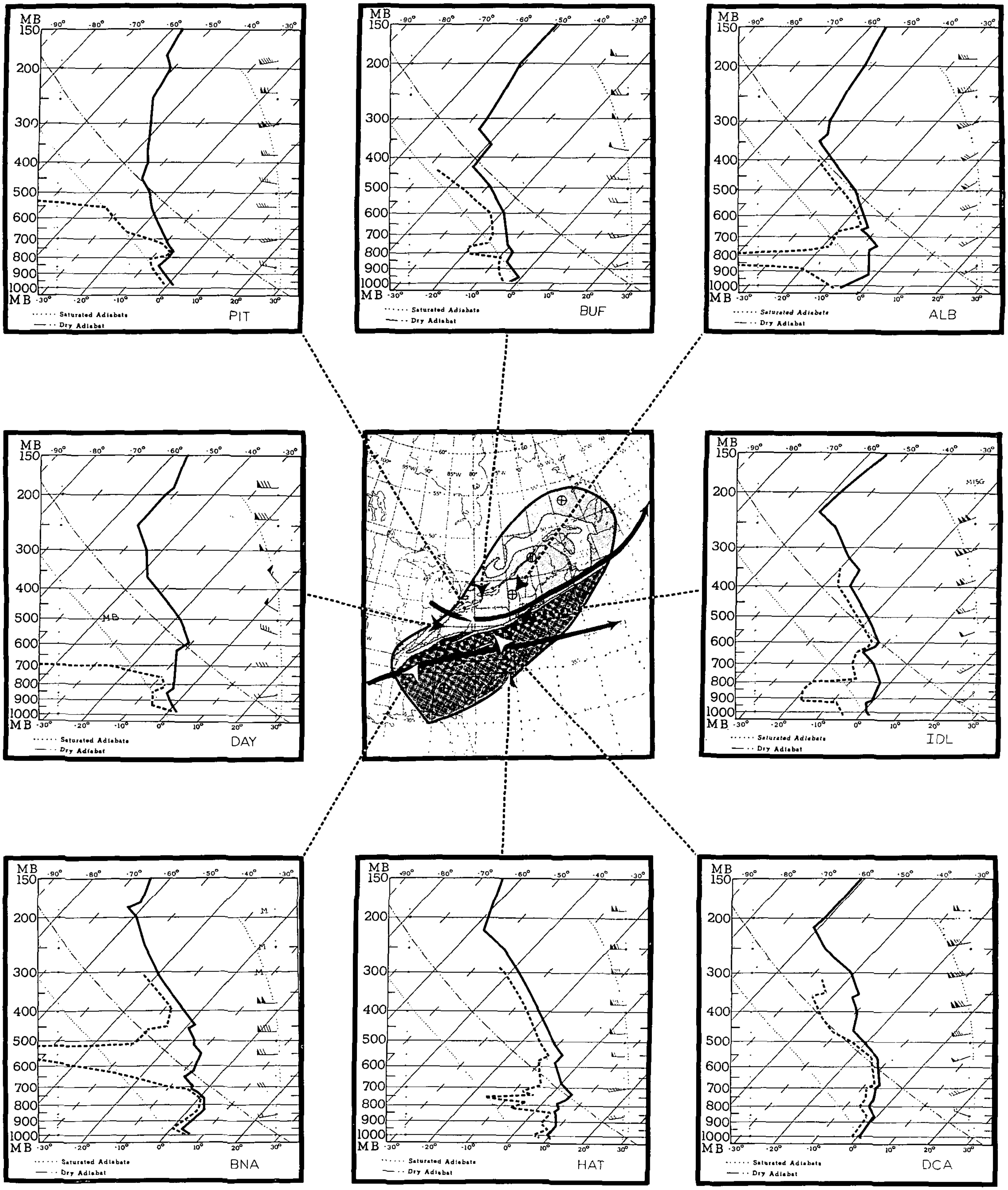

FIGURE 6.—Nephanalysis of pass 0922 and plotted radiosonde observations for 1200 GMT, November 20 in the vicinity of the jet streams.

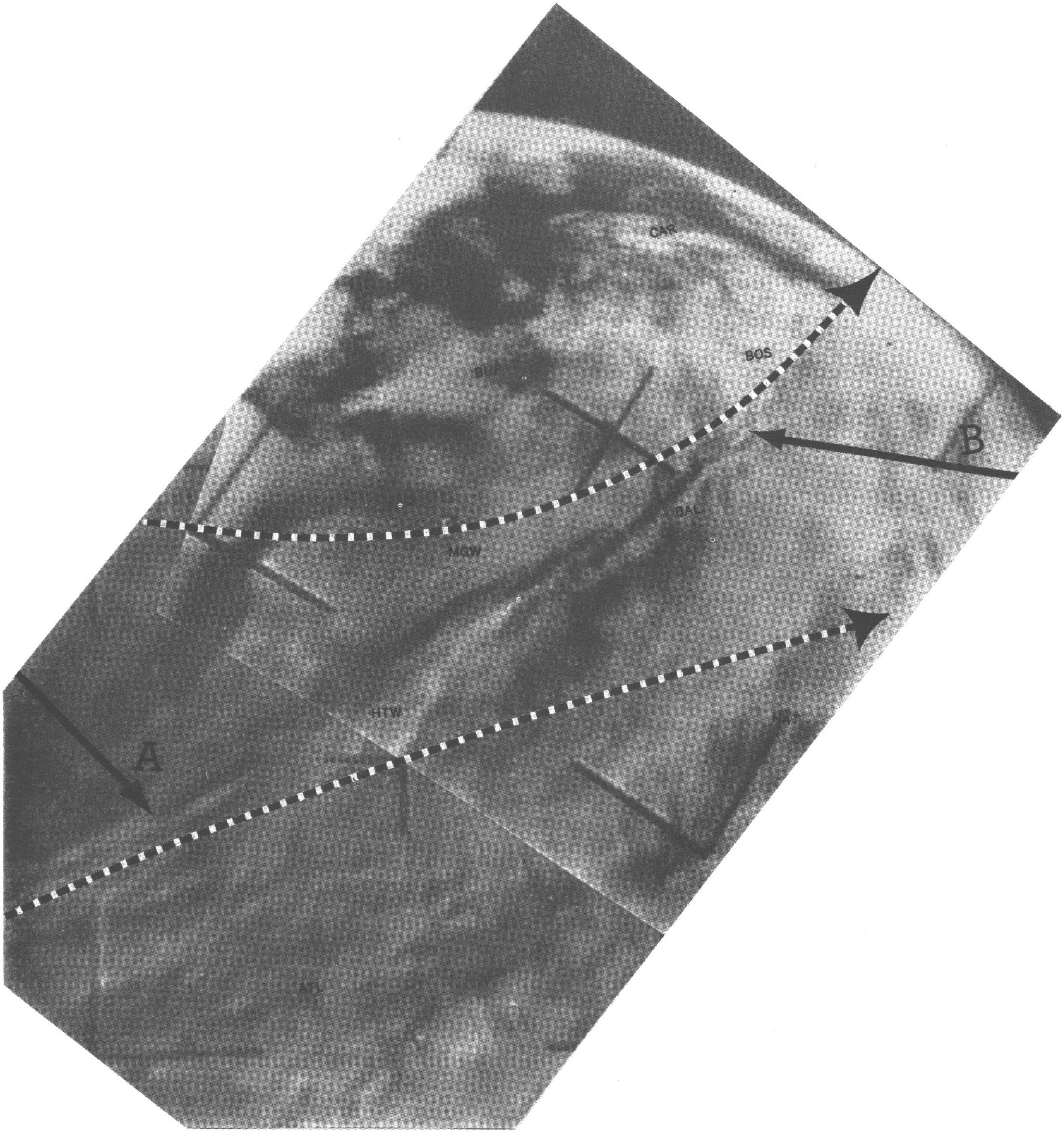

FIGURE 7.—Mosaic of pass 2209 (TIROS V, 1448 GMT, November 20, 1962). The dashed lines indicate the 200-mb. jet stream positions at 1200 GMT. The dark streak seen in figure 4 is still visible here 53 min. later, extending from the head of arrow A to the head of arrow B.

An attempt was made to ascertain whether the feature which appears in this picture as the dark streak was actually the shadow cast by the higher cirrus clouds south of the jet on the top of an overcast layer of lower clouds extending to the north. To determine if this shadow would have been of sufficient width to be detected by the satellite, the width of a shadow cast by cirrus in this situation was calculated using a solar elevation angle at

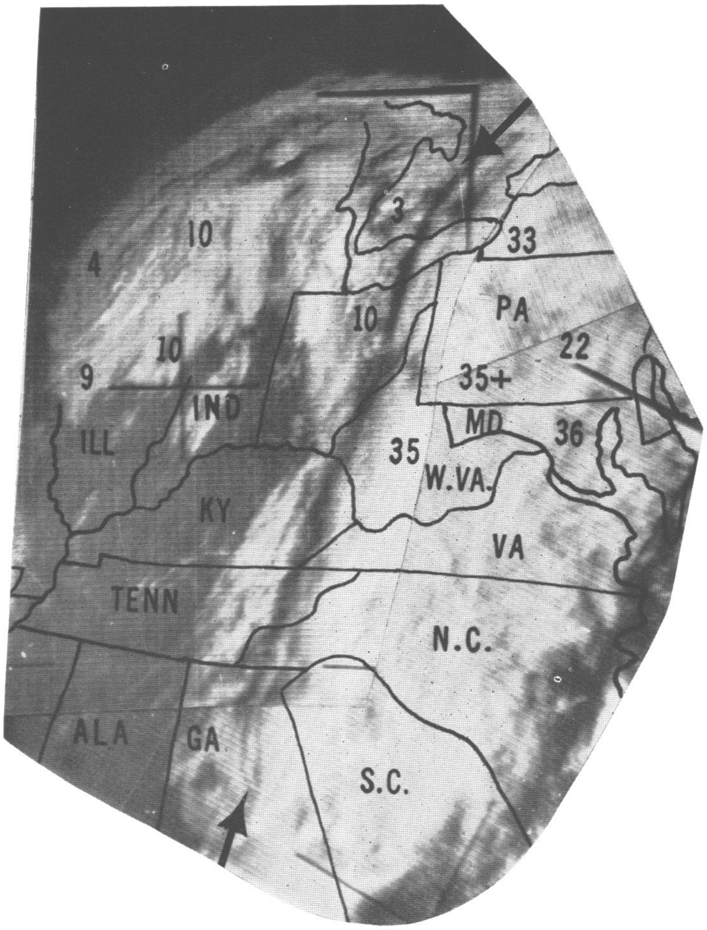

FIGURE 8.—Mosaic of pass 1534 (TIROS V, 1312 GMT, October 4, 1962). The state borders have been superimposed and the height of the cloud tops as reported by pilots are shown in thousands of feet. Note the dark streak which extends from Georgia to southern Quebec.

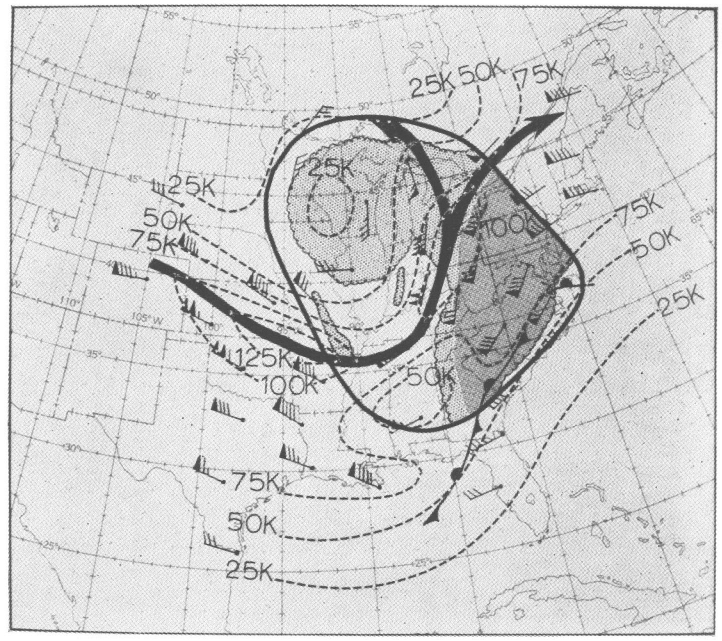

FIGURE 9.—Nephanalysis of pass 1534 (TIROS V, 1312 GMT, October 4, 1962) with the NMC maximum wind data and isotachs superimposed.

Baltimore of 18°, and a height difference of 25,000 ft. The width of the shadow that could be cast was found to be about 15 mi. The angle between the line of sight of the satellite and the local vertical above the edge of the high cloud in this case is about 9°, giving 14 mi. as the width of the shadow visible to the satellite. This is well within the resolution of the TIROS camera. The width of the dark streak in this area is about 20 mi. as measured on the photographs. Twenty miles is, of course, an approximation, but is of the same order of magnitude as the calculated width. The wider portion of the streak farther west cannot be explained by this reasoning and must therefore be an area with an actual break in the clouds. This break is indicated by the surface reports in southwestern Ohio (fig. 5).

Figure 7 is a mosaic of pass 2209 which took place about an hour after pass 0922. The streak is still very distinct and even though there was a westerly flow of about 100 kt. above 20,000 ft., very little change in shape took place in the cloud features during this time.

Another example of the appearance of the jet cloud shadow is seen in the mosaic of pass 1534, TIROS V, 1312 GMT, October 4, 1962 (fig. 8). This shows a vortex over Wisconsin associated with a cold, cut-off upper-level Low. A dark streak is visible in the cloud picture extending from Georgia northward across Lake Erie. The maximum wind analysis (fig. 9) shows the jet core at 1200 GMT, 3 hr. before the picture, from central Tennessee northeastward to Lake Erie and then to the east. Here again, the dark streak appears to be the shadow cast by the higher cloud deck to the east of the jet on the lower clouds which extend to the west. Pilot reports (fig. 8) of the reported tops of the clouds show a dramatic drop across the jet from 35,000 ft. over Pennsylvania to 10,000 ft. or less to the west. A height difference of 25,000 ft. between the two cloud layers and a solar elevation angle of 17° would produce a shadow 16 mi. wide over eastern Kentucky at the time of the picture. In this case, the angle between the line of sight of the satellite and the local vertical above the edge of the cirrus cloud shield is about 41°. Because of the position of the satellite relative to the shadow, the width of the shadow which can be viewed by the satellite is about 12 mi. Figure 9 is a nephanalysis of pass 1534 and shows the jet stream position relative to the high cloud deck as viewed by the satellite.

An example in which the edge of the high cloud along the jet core is not so obvious is shown in figure 10b (pass 0018, TIROS VI, 1321 GMT, September 19, 1962. Here only a faint line is visible in the cloud picture where the higher cloud deck ends near the jet core. Figure 11

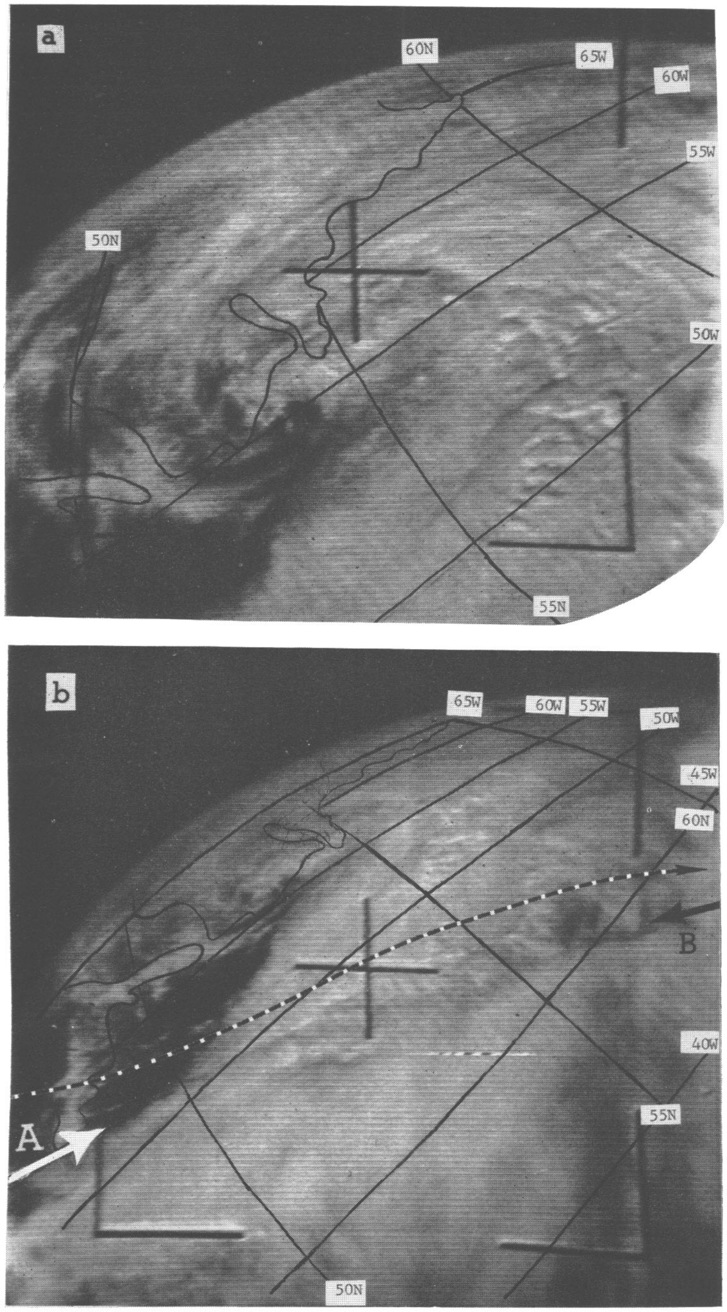

FIGURE 10.—(a) Picture from pass 0018 (TIROS VI, 1321 GMT, September 19, 1962) which shows in detail the texture of the cloud pattern on the cold side of the jet stream. This is the area shown in the northern half of figure 10b. (b) Picture from pass 0018 (TIROS VI, 1321 GMT, September 19, 1962). In this picture a dark streak extends from southeastern Newfoundland, head of arrow A, to 57° N., 44° W., head of arrow B. This streak is correlated with the position of the jet stream which passes to the south of a Low centered along the east coast of Labrador. The dashed line marks the 200-mb. jet stream position.

shows the 200-mb. wind field and jet stream position 1 hr. prior to the time the pictures were taken.

Figure 10a views the area seen in the northern half of figure 10b and gives a more detailed picture of the cloud

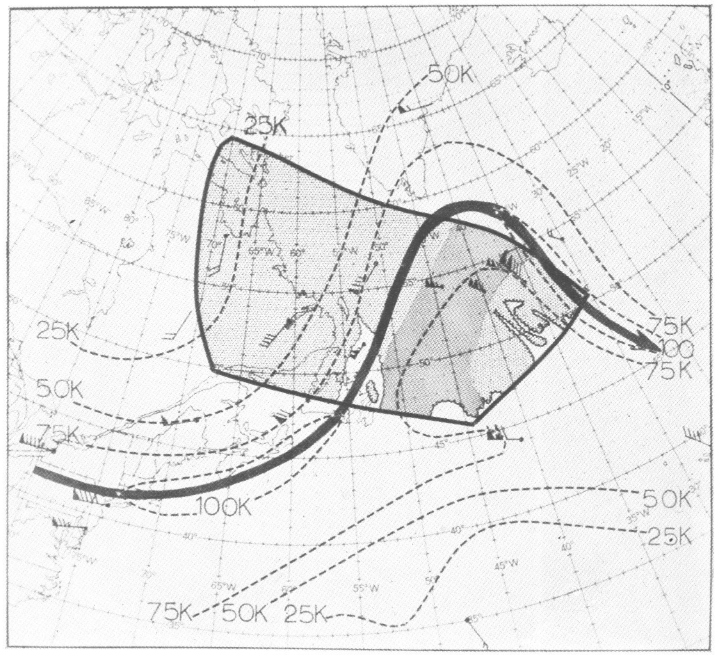

FIGURE 11.—Nephanalysis of pass 0018 with the 200-mb. winds and isotachs for 1 hr. earlier added. The heavy dark line marks the 200-mb. jet stream position.

pattern on the cold side of the jet stream. These two pictures reveal characteristics in the texture of the clouds on both the cold and warm sides of the jet which allow some reasonable conclusions to be drawn about the relative heights of the clouds being viewed.

Note the contrast in the texture of the upper surface of the clouds to the right and left of the jet stream. The clouds on the cold side of the jet stream (fig. 10a) have a "pebbled" appearance (as at 57° N., 51° W.), caused by the protrusion of building cumuli through the lower solid overcast, while on the warm side of the jet stream (fig. 10b), the clouds take on a much smoother appearance. Notice that the break in the low clouds which begins at 52° N., 39° W. (fig. 10b) gradually becomes less visible toward the north and is obscured by the smoother-looking upper cloud deck, near 56° N., 44° W. This break can again be seen on the cold side of the jet stream at 56° N., 61° W.

No pilot reports were available for this last case, but the evidence in the cloud pictures themselves suggests that we are seeing here again the cirrus cloud shield, which Kadlec, McLean, Conover, and others have shown exists south of the jet core, ending abruptly near the region of strongest wind.

Further study will be necessary on a hemispheric basis to refine the relationship to the jet stream of the cloud patterns observed by TIROS. The cases presented here suggest that TIROS pictures when properly interpreted can become a powerful tool in identifying and positioning the jet stream and its associated clouds in data sparse areas.

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